Journal of Psychiatric Research 60 (2015) 148–155

Contents lists available at ScienceDirect

Journal of Psychiatric Research

journal homepage: www.elsevier.com/locate/psychires

Does objectively assessed sleep at five years predict sleep and psychological functioning at 14 years? – Hmm, yes and no!

Serge Brand [a, b, *], Martin Hatzinger [c], Christina Stadler [d], Margarete Bolten [d], Agnes von Wyl [e], Sonja Perren [f], Kai von Klitzing [g], Stephanie Stadelmann [g], Edith Holsboer-Trachsler [a]

[a] Psychiatric Clinics of the University of Basel, Center for Affective, Stress and Sleep Disorders, Basel, Switzerland
[b] Department of Sport and Health Sciences, Sport Science Section, University of Basel, Basel, Switzerland
[c] Psychiatric Services Solothurn, Department of Adult Psychiatry, Solothurn, Switzerland
[d] Psychiatric Clinics of the University of Basel, Department of Child and Adolescent Psychiatry, Basel, Switzerland
[e] Institute of Psychology, University of Zurich, Switzerland
[f] Jacobs Center for Productive Youth Development, University of Zurich, Switzerland
[g] Department of Child and Adolescent Psychiatry, Psychotherapy, and Psychosomatics, University of Leipzig, Germany

ARTICLE INFO

Article history:
Received 29 May 2014
Received in revised form
25 August 2014
Accepted 7 October 2014

Keywords:
Longitudinal study
Sleep
Childhood
Adolescence
Prediction
Psychological functioning

ABSTRACT

Background: We tested the hypothesis that objectively assessed sleep at kindergarten level predicts sleep and psychological functioning in adolescence.
Method: Thirty-seven adolescents aged 14 years (SD = 1.3), of 67 participants assessed as preschoolers, took part in a follow-up study nine years later. Participants completed a series of questionnaires related to sleep and psychological functioning. Sleep-EEG clusters of poor, normal and good sleepers assessed as children nine years earlier were used as predictors for subjective sleep and psychological functioning in adolescence.
Results: At the age of 14, those who were normal and good sleepers rather than poor sleepers at the age of five had more positive psychological functioning on dimensions including mental toughness, peer relationship, self-esteem, and perceived stress, but did not differ in current sleep patterns.
Conclusions: Objectively assessed sleep patterns at the age of five are predictive of aspects of psychological functioning during adolescence.

1. Introduction

Favorable and restoring sleep is associated with a broad range of positive psychological outcomes (Gregory and Sadeh, 2012; Brand et al., 2014a, 2014b; Brand and Kirov, 2011). This holds true for infants (Brand et al., 2011), children (Gregory and Sadeh, 2012; Dewald et al., 2010), adolescents (Brand et al., 2014a, 2014b) and adults (Tasali et al., 2014). On the flip side, poor sleep is also associated with a broad range of psychological problems, as observed from cross-sectional studies. Longitudinal studies also show that poor sleep at time one may predict poor sleep and poor psychological functioning in later life. Table 1[1] reports the state-of-play regarding the longer term stability of poor sleep and the relation between poor sleep and poor psychological functioning over time, separately for the following developmental periods: infancy to childhood, early to later childhood, childhood to adolescence, childhood to adulthood, early to later adolescence, and adolescence to adulthood.

As indicated in Table 1, the overall pattern suggests that poor sleep at time one (whether this is infancy, childhood, or adolescence) has an influence of sleep and psychological functioning at a later time point (childhood, adolescence, adulthood). However, Table 1 also shows that sleep has predominantly been assessed via subjective child and parent reports, whereas use of objective sleep

* Corresponding author. Center for Affective, Stress and Sleep Disorders, Psychiatric Clinics of the University of Basel, Wilhelm Klein-Strasse 27, 4027 Basel, Switzerland. Tel.: +41 61 325 51 14; fax: +41 61 325 55 53.
E-mail address: serge.brand@upkbs.ch (S. Brand).

[1] Please note that in Table 1 we reported the most salient longitudinal studies, and we do not offer a complete and thorough review.

http://dx.doi.org/10.1016/j.jpsychires.2014.10.007
0022-3956/

Table 1
Overview of studies focusing on the impact of sleep characteristics on sleep and psychological functioning at long-term.

Authors	Children's/participants' characteristics at first assessment		Children's/participants' characteristics at second assessment			
	N; age	Type of sleep assessment	*N*; age; time lapse	Type of sleep assessment	Type of psychological assessment	Key messages
Infancy to childhood						
Hemmi et al., 2011	Infancy	Parent report	childhood	Parent report		Poor sleep, crying and feeding behavior predict behavioral problems in childhood
Early to later childhood						
Hatzinger et al., 2013b	$N = 67$; 5.4 years	Sleep-EEG	$N = 58$; 6.4 years/about 12 months	Sleep-EEG	SDQ, BPI	Clusters of poor, normal and good sleepers Objective sleep remains stable over time Poor sleep at T1 predicts poor sleep and poor psychological functioning at T2
Hatzinger et al., 2014	$N = 83$; 5.4 years	Actigraphy	$N = 73$; 6.4 years/about 12 months	Actigraphy	SDQ, BPI	Clusters of poor, normal and good sleepers Objective sleep remains stable over time Poor sleep at T1 predicts poor sleep and poor psychological functioning at T2
Johnson et al., 2000	$N = 823$; 6 years	Parent and teacher report CBCL	$N = 717$; 11 years	Parent and teacher report CBCL	CBCL	Sleep disturbances at age 6 did not predict depression at age 11
Quach et al., 2009	$N = 4460$; 4–5 years old	Parent report	$N = 4460$; 6–7 years old	Parent report	Parent and teacher report	Persistent and incident sleep problems predicted poor health-related quality of life
Simola et al., 2014	$N = 904$; pre-schoolers	Parent report SDSC	$N = 470$; 9 years old	Parent report CBCL	CBCL	Persistent sleep problems were related to psychosocial symptoms such as aggression, social and attention problems and anxious/depressed mood
Childhood to adolescence						
Bub et al., 2011	$N = 251$; 8–9 years old	Self-report	$N = 214$; 9–10 years old	Self-report	Cognitive performance	Poor sleep predicted lower cognitive performance
El-Sheikh et al., 2010	$N = 251$; 8.23 years old	Self-report	$N = 194$; 10.28 years (third wave)	Self-report	TSCC	Higher initial levels and increases in sleep problems predicted higher symptoms of depression and anxiety
Fichter et al., 2009	$N = 269$; 5.8 years old	Experts' interviews	$N = 220$; 18 years old	Experts' interviews	Experts' psychiatric interviews	Increased levels of somatic symptoms, fatigue, irritability, sleep disturbances, depression, anxiety and worry as well as phobic symptoms in childhood/ adolescence were related to a higher risk of suffering from a psychiatric disorder in adulthood.
Friedman et al., 2009	$N = 897$; 4 years old	Parent report CBCL	$N = 568$; 17 years old	Parent report CBCL	Cognitive testing	Poor sleep was not related to later cognitive performance; those with steeper decrease of sleep problems showed better general executive control
Gozal and Pope 2001	$N = 1913$; 5–9 years	Parent report	$N = 1588$; 13–16 years	Parent report	Cognitive testing	Focus on snoring: sleep-disordered breathing was associated with lower academic scores during adolescence
Gregory et al., 2009	$N = 1037$; 7 years old	Parent report Self-administered questionnaire	$N = 972$; 11 years old	Parent report Self-administered questionnaire	Parent report Self-administered questionnaire	Childhood sleep disturbances predicted poor neuropsychological performance in adolescence
Childhood to adulthood						
Gregory et al., 2005	$N = 1037$; childhood	Parents report self-administered questionnaire	$N = 943$; adults	Self-report	Psychiatric and diagnostic interview	Poor sleep during childhood predicted depressive symptoms in adulthood
Ong et al., 2006	$N = 220$; 6–23 years	Parent report Self-administered questionnaire	$N = 164$; 20 years later	Self-report	Self-report	Higher insomnia scores during childhood predicted mood and anxiety disorders
Touchette et al., 2012	$N = 2498$; 4–16 years	Self-report	$N = 1103$; 28.8 years old	Self-report	Self-report	Sleep problems at 10 years predicted externalizing problems 20 years later
Wong et al., 2010	$N = 294$; 5 years	Parent report CBCL	$N = 294$; 15–17 years	Self-report YSR	Self-report	Sleep difficulties in kindergarten predicted higher alcohol problems as young adults
Early to later adolescence						
Kaneita et al., 2009	$N = 698$; 11 years	Self-report PSQI	$N = 516$; 13 years	Self-report PSQI	General health questionnaire	Poor sleep predicted persisting and emerging stress and poor sleep

(*continued on next page*)

Table 1 (*continued*)

Authors	Children's/participants' characteristics at first assessment		Children's/participants' characteristics at second assessment			
	N; age	Type of sleep assessment	*N*; age; time lapse	Type of sleep assessment	Type of psychological assessment	Key messages
Meijer et al., 2010	*N* = 650; 12–15 years	Self report self-administered questionnaire	*N* = 493; 15 years old	Self report self-administered questionnaire	Self report self-administered questionnaire	Sleep duration and sleep quality are not associated Poor sleep is associated with problem behavior
Roberts et al., 2009	*N* = 3134; 11–17 years old	Self report self-administered questionnaire	*N* = 3134; 12–18 years old	Self report self-administered questionnaire	Self report self-administered questionnaire	Poor sleep predicted increased risk for depression and poor academic performance
Roberts and Duong, 2013	*N* = 3134; 11–17 years old	Self report self-administered questionnaire	*N* = 3134; 12–18 years old	Self report self-administered questionnaire	Self report self-administered questionnaire	Poor sleep and depressive symptoms are reciprocally related
Adolescence to adulthood						
Asarnow et al., 2014	*N* = 2700 at ages 7–12 and 8–12	Self report self administered questionnaire	*N* = 2684, ages 18–26	Self report self administered questionnaire	Self report self administered questionnaire	Late school year bedtime in Wave I (1994–1995) was associated with worse educational outcomes and emotional distress 6–8 years
Roane and Taylor 2008	*N* = 4494; 15 years old	Self-report	*N* = 3582; 21.25 years old	Self-report	Self-report	Adolescent insomnia predicted psychological problems in adulthood
Wong and Brower 2012	*N* = 6504; 16 years old	Self-report	*N* = ?; 21 years old	Self-report	Self-report	Poor sleep predicted depression and suicidal thoughts Poor sleep predicted suicidal thoughts and suicide attempts

Notes: TSCC = Trauma Symptoms Check List, CBCL = Child Behavior Check List, PSQI = Pittsburgh Sleep Quality Index, YSR = Youth Self Report.

measures is much less common (for an exception see the studies of El-Sheikh et al., 2010).

The current study expands upon the existing literature in five ways. In contrast to large-scale surveys using self-ratings, parent and teacher rating questionnaires (for an exception see El-Sheikh et al., 2010), we assessed a small sample of 5.4 year-old pre-schoolers, 1) using objective sleep-EEG-recording, 2) collecting emotional, cognitive and behavioral data using self-ratings at the age of 14 years, that is, nine years later, and 3) focusing also on the association between sleep and exercise behavior at long term. Most importantly, to assess adolescent participants' psychological functioning, a broad variety of psychological dimensions including perceived stress, coping, mental toughness, and general psychological and physiological well-being were assessed, along with subjective sleep.

Based on previous research (see Table 1), we expected that objectively assessed good sleepers at the age of 5.4 years of life (SD = 0.44) would report better psychological functioning than their counterparts with normal and poor sleep parameters.

As regards the association between sleep and exercise behavior, we note that a large body of research shows that regular moderate to vigorous exercising is favorably and also causally associated with increased sleep both in adolescents and adults (e.g. Brand et al., 2014; Dworak et al., 2008; Gerber et al., 2010; Kalak et al., 2012a, 2012b; Lang et al., 2013). However, research focusing on the immediate effect of sleep on exercise behavior is scarce (Chennaoui et al., 2014), and no study has addressed so far the scientific question as to what extent objectively assessed sleep behavior might predict exercise behavior at very long time. Accordingly, we introduced this issue as a further research question.

2. Method

2.1. Sample

Pre-school children, who participated in a previous study (Perren et al., 2006; Hatzinger et al., 2007, 2008, 2010, 2012, 2013a, 2013b, 2014; von Klitzing et al., 2012), were re-contacted and followed-up at the age of 14. Of the 67 participants for whom sleep-EEG recordings were available at 5.4 years (SD = 0.44), 37[2] (55.22%; mean age: *M* = 14.02; SD = 1.20; 56.8% female participants) could be followed-up and agreed to participate in the new study.[3] The purpose of the follow-up study was fully explained to the adolescents and their parents. The parents were asked to sign an informed consent form before their children entered the study. The experimental protocol was carried out in accordance with the Declaration of Helsinki, and was approved by the local ethics committee.

2.2. Procedure

Once written informed consent was secured, participants were asked to complete a booklet consisting of a set of different questionnaires related to demographic data, psychological functioning and sleep, as described in more detail below. After completion (20–30 min duration), participants received a voucher of CHF 20.00 (about USD 20.00) for the iTunes® store. Next, the current data were matched with the existing sleep-EEG data collected at the age of 5.4 years (SD = 0.44; Hatzinger et al., 2008).

2.3. Sleep-EEG clusters

As described elsewhere in more detail (Hatzinger et al., 2008, 2013a, 2013b), pre-schoolers' sleep was recorded with the ambulatory EEG system (Oxford Medilog) during one night at the children's home. The first adaptation night served to familiarize the children with the recording, including attachment of the electrodes, while no registration was performed. Electro-

[2] Of the 30 adolescents approached who did not participate, 14 were lost to follow-up (that is, we found no way to get in contact with them); 16 did refuse to participate: three were not interested anymore in the study; 13 found the study interesting and worth to participate, though the main reasons for no-participations were time constraints and school-related issues.

[3] No significant differences in age, gender, sleep parameters and psychological functioning at the age of 5.4 years were observed between participants and non-participants of the present study.

encephalographic registration occurred the second night. Electrodes for polygraphic recordings (electroencephalogram: C3-A2, C4-A1, electromyogram: two electrodes on the chin, electrooculogram: two electrodes on the right and left side) were fixed the evening before registration and removed the next morning. Sleep polygraphs were visually analyzed by two experienced raters according to standard procedures (Rechtschaffen and Kales, 1968). Sleep parameters were analyzed according to the definitions in the standard program described by Lauer et al. (1991). Next, at this initial assessment (Hatzinger et al., 2008), based on objectively assessed sleep variables, children were grouped into poor (40%; $n = 27$), normal (27%; $n = 18$) or good (33%; $n = 22$) sleepers.[4] To this end, following Sadeh et al. (2000) and applying the DSM-IV-TR criteria for insomnia sleep disorders (DSM-IV-TR, APA, 2000), participants were clustered with respect to their baseline values on the following three variables as a starting point for cluster analysis: SOL (sleep onset latency), SPT (sleep period time) and the total time of awakenings after sleep onset. Cluster analyses were performed applying the method of linkage between groups and Euclidean distance as measure (Anderberg, 1973). This factor, Group, served as independent variable in a series of ANOVAs while current psychological assessment and subjective sleep variables were introduced as dependent variables. Post-hoc analyses for multiple testing were performed with *p*-values corrections after Games-Howell, as this procedure does not rely on equal sample sizes.

2.4. Materials

2.4.1. Mental toughness

Participants were asked to fill in the 18-item Mental Toughness Questionnaire (MTQ18; Clough et al., 2002; German version: Gerber et al., 2012; Gerber et al., 2013a, 2013b). The MTQ18 is the short version of the MTQ48 questionnaire.[5] Answers on the MTQ18 are given on five-point Likert-type scales ranging from 1 (=strongly disagree) to 5 (=strongly agree). Items were summed, with higher scores reflecting greater MT (Cronbach's alpha = .94).

2.4.2. Psychological functioning

Participants completed the KID-SCREEN 52 (Ravens-Sieberer et al., and the KDSCREEN Group, 2008). The questionnaire consists of 52 items focusing on ten different domains of children's and adolescents' functioning: physical functioning, psychological functioning, moods and emotions, self-perception, autonomy, parent relations and home life, child's financial resources (pocket money or earning money from part time jobs), social support and peers, school environment, and social acceptance. Answers are given on 5-point Likert scales, with the anchor points 1 (=not at all) and 5 (=extremely/always). The 10 domains are further aggregated to provide the following subscales: physical wellbeing, psychological wellbeing, relationship with parents and autonomy, relationship with peers, school environment, and social acceptance. A global health-related quality of life index is also calculated. Higher mean scores reflect better functioning in the respective domains (Cronbach's alpha for the overall index = .93).

2.4.3. Perceived stress

The Perceived Stress Scale (Cohen et al., 1983) consists of 10 items and was used to determine perceived overall stress occurring over the previous month. Answers were given on five-point rating scales ranging from 1 (never) to 5 (very often), with higher scores reflecting greater perceived stress (Cronbach's alpha = .89).

2.4.4. Coping with stress

The questionnaire consists of 18 items and assesses positive and negative coping strategies (Janke and Erdmann, 2008). Positive coping strategies are those that reduce tension in both the short and the long term, including minimizing the situation, controlling the situation, and self-instruction. Negative coping strategies are those that reduce tension in the short term but increase stress in the long term, including social withdrawal, rumination, and resignation. Answers were given on five-point rating scales ranging from 1 (very unlikely) to 5 (very likely). The higher the score, the more pronounced is the coping strategy (Cronbach's alpha = .87). Two composite mean scores were computed reflecting positive and negative coping strategies, respectively. To further calculate an overall score for coping strategies, the ratio between positive and. negative coping was calculated, with higher ratios reflecting a greater reliance on positive as opposed to negative coping strategies.

2.4.5. Moderate to vigorous physical activity (PA)

To assess physical activity, participants were asked on how many days per week they exercised or participated in (high intensity) activities and sports. The response categories ranged from 0 to 7 days. In addition, participants were asked to indicate the average duration (per day) for the days they engaged in these activities. Multiplication of frequency and duration scores resulted in an estimate of hours invested weekly in vigorous PA. In addition, participants were asked to indicate how many days per week they engaged in moderate PA. Again, an additional question asked about duration per day in order to estimate their weekly engagement (hours/week) in moderate PA. All items were taken from the International Physical Activity Questionnaire (Craig et al., 2003). Validity of such general items is considered acceptable in samples of adolescents (Hagströmer et al., 2008). Ottevaere et al. (2011) showed that the IPAQ is able to predict cardiorespiratory fitness among adolescents as successfully as data from accelerometers. Following the IPAQ-guidelines (see www.ipaq.ki.se/scoring.pdf), daily PA values of 10 min or lower were set at 0, because it is assumed that daily PA values of 10 min or lower have no impact on health. Additionally, reports of daily PA higher than 180 min/day were limited to 180 min/day, leading to a maximum moderate or vigorous weekly PA of 21 h.

2.4.6. School marks

To provide a general indication of current school performance, participants answered the following question: “Overall, your current school marks are below the class average (=1), equal to the class average (=2), above the class average (=3), much above the class average (=4)”.

2.4.7. Sleep quality/sleep disturbance

The Insomnia Severity Index (ISI; Bastien et al., 2001) is a 7-item screening measure for insomnia and an outcome measure for use in treatment research. The items, answered on 5-point rating scales (0 = not at all, 4 = very much), refer in part to DSM-IV (Diagnostic and Statistical Manual of Mental Disorders) criteria for insomnia

[4] At follow-up nine years later, the following attrition rates were observed: poor sleepers: from 27 to 9 participants (66.6% attrition rate); normal sleepers: from 18 to 10 participants (44.5% attrition rate); good sleepers: from 22 to 18 participants (18.2% attrition rate).

[5] Whereas the short version provides an overall score for mental toughness, the original and long version measures the subcomponents: challenge (e.g., ‘Challenges usually bring out the best in me.’), commitment (e.g., ‘I don't usually give up under pressure.’), emotional and life control (e.g., ‘Even when under considerable pressure I usually remain calm’; ‘I generally feel in control.’), and confidence ([interpersonal confidence]: ‘I usually take charge of a situation when I feel it is appropriate.’; [confidence in ability]: ‘I am generally confident in my own abilities.’).

Table 2
Descriptive and inferential statistics for the psychological functioning, sleep and physical activity variables at age 14 years, separately by the clusters previously established at age 5.4 years of poor, normal and good sleepers.

N	Groups			Statistics	
	Good sleepers [*G*]	Normal sleepers [*N*]	Poor sleepers [*P*]	ANOVAs *F*-values	Post-hoc analyses
	18	10	9		
Perceived stress	4.5 (1.79)	2.80 (1.39)	5.67 (2.45)	5.89***	*N* > *G*, *P*; *P* < *N*, *G*
Coping with stress					
Positive coping strategies	10.67 (4.37)	8.00 (3.59)	9.22 (5.52)	<1.5	
Negative coping strategies	9.00 (2.56)	9.64 (1.99)	7.89 (2.54)	<1.5	
Mental toughness	21.06 (3.93)	27.40 (2.79)	20.22 (6.26)	8.52***	*N* > *G*, *P*; *P* < *N*, *G*
School marks	2.91 (0.57)	3.30 (0.39)	2.83 (0.31)	2.89*	*N* > *B*, *P*
KS52: Feelings	3.10 (0.59)	3.84 (0.16)	2.91 (0.48)	10.54***	*N* > *G*, *P*; *P* < *N*, *G*
KS52: Mood	0.69 (0.65)	0.57 (0.39)	0.87 (1.22)	<1.5	
KS52: Self-esteem	2.19 (0.49)	1.80 (0.19)	2.00 (0.53)	3.49*	*N* > *B*, *P*
KS52: Leisure time	3.06 (0.70)	3.25 (0.50)	3.03 (0.69)	<1.5	
KS52: Family environment	3.34 (0.60)	3.62 (0.39)	3.06 (0.31)	<1.5	
KS52: Financial resources	3.33 (0.80)	3.87 (0.28)	3.56 (0.37)	<1.5	
KS52: Peer relationship	2.93 (0.65)	3.47 (0.34)	2.98 (0.56)	3.09*	*N* > *B*, *P*
KS52: School environment	2.88 (0.70)	3.20 (0.50)	2.54 (0.73)	<1.5	
KS52: Bullying	0.39 (0.65)	0.70 (1.22)	0.67 (1.35)	<1.5	
KS52: Psychological well-being	1.99 (0.33)	2.07 (0.13)	1.93 (0.44)	<1.5	
KS52: relationships and autonomy	3.24 (0.51)	3.47 (0.07)	3.40 (0.25)	<1.5	
KS52: Physical well-being	2.68 (0.69)	3.45 (0.54)	2.58 (0.89)	4.76**	*N* > *B*, *P*
Subjective sleep	5.56 (0.89)	6.78 (1.25)	6.06 (0.89)	<1.5	
Moderate to vigorous physical activity	3.17 (2.36)	4.80 (2.44)	4.00 (2.60)	<1.5	

Notes: KS52 = Kidscreen-52 questionnaire. Degrees of freedom: always (2, 36). * = $p < .05$, ** = $p < .01$; *** = $p < .001$.

(American Psychiatric Association, 2000) by measuring difficulty in falling asleep, difficulties remaining asleep, early morning awakenings, increased daytime sleepiness, impaired daytime sleepiness, impaired daytime performance, low satisfaction with sleep, and worrying about sleep. The higher the overall score, the more the respondent is assumed to suffer from sleep disturbances (Cronbach's alpha = .92).

2.5. Statistical analysis

As mentioned, the sleep clusters were labeled as poor, normal and good sleepers. This factor Group served as independent variable in a series of ANOVAs while current psychological assessment and subjective sleep variables were introduced as dependent variables. Post-hoc analyses for multiple testing were performed with *p*-values corrections after Games-Howell, as this procedure does not rely on equal sample sizes. Effect sizes are indicated with the partial eta squared (η^2), with $0.059 \geq \eta^2 \geq 0.01$ indicating small [*S*], $0.139 \geq \eta^2 \geq 0.06$ indicating medium [*M*], and $\eta^2 \geq 0.14$ indicating large [*L*] effect sizes. The nominal alpha-level was set at 0.05. Statistical analyses were performed with SPSS® 20.0 (IBM Corporation, Armonk NY, USA) for Apple MacIntosh®.

3. Results

3.1. Clusters of poor, normal and good sleepers at the age of five years and psychological functioning, sleep and physical activity at the age 14 years

Table 2 gives descriptive and inferential statistics for the psychological functioning, sleep and physical activity variables at age 14 years, separately by the clusters previously established at age 5.4 years of poor, normal and good sleepers.

Significant mean differences were found for Perceived stress, Mental toughness, School marks, Moods and Emotions, Self-perception, Financial resources, Social support and peers, School environment, and for the Global health-related quality of life index. Post-hoc analyses with *p*-values corrections after Games-Howell revealed that *normal* sleepers at the age of 5.4 years, compared to *good* and poor sleepers at the age of 5.4 years, had better or more positive scores for Perceived stress, School marks, Feelings and Emotions, Financial resources, Social support and peers, School environment, and for the Global health-related quality of life index. Further, post-hoc analyses after Games-Howell revealed that *good* sleepers at the age of 5.4 years, compared to normal and poor sleepers at the age of 5.4 years, had higher or more positive scores for Mental toughness, and Self-perception. No statistically significant group differences were found for moderate to vigorous physical activity, subjective sleep (ISI), coping with stress, leisure time activities, parent relation and home life, social acceptance, general psychological well-being, relationships or autonomy.

4. Discussion

The key findings of the present longitudinal study are that sleep patterns objectively assessed at the age of 5.4 years (childhood) were related to psychological functioning at the age of 14 years (adolescence), and that, partly against expectations, *not good* but *normal* sleepers at the age of 5.4 years had by self-report more favorable psychological functioning as teenagers, compared to both the good and poor sleepers.

Taking a closer look to the pattern of results, we believe that our findings are generally in accord with numerous previous studies (see Table 1). Accordingly, shifting the focus from good and favorable sleep to poor and unfavorable sleep, our findings lend support to the notion that poor sleep at an earlier stage of life (here: early childhood) seems to be associated with unfavorable psychological functioning later in life (here: adolescence). However, in our view the present study expands upon previous research in that sleep was objectively assessed via sleep-EEGs and in that broader facets of psychological functioning were assessed. Thus, the present results add to the current literature in important ways.

However, two issues arise from the present study. First, it remains unclear why sleep in pre-school years should predict psychological functioning in adolescence. That is, what is the

underlying psychological, and presumably also physiological, transmission belt? Second, why, against expectations, do *normal* sleepers outperform *good* and not just *poor* sleepers in some domains of psychological functioning?

As regards the first issue, the underlying psychological and physiological mechanisms, we offer four possible explanations. First, Riemann et al. (2010) claim that sleep disturbances are caused and maintained by dysfunctional cognitive-emotional processes. More specifically, Riemann et al. (2010) propose that psychological stress, along with worrying and rumination, lead to sleep disruptions (i.e., delayed sleep onset latency, more awakenings after sleep onset, early awakening in the morning). The model proposed by Riemann et al. (2010) does not clarify, if it is applicable already to pre-schoolers. Though highly speculative, however, one may claim that already pre-schoolers have to cope with and face demanding psychosocial situations (that is, they have to solve problems) as also older children, adolescents and adults do. In parallel to these cognitive-emotional processes and sleep disruptions, physiological processes such as increased secretion of cortisol and orexin, and decreased secretion of serotonin, lead in the longer term to acute cortical arousal and a deterioration in homeostasis. On this basis, it is possible that these dysfunctional cognitive-emotional processes, along with changed psychophysiological processes, persist into adolescence producing the pattern of results observed in the present study. Second, poor sleep during childhood may also be caused or at least maintained by inadequate parental behavior (see El-Sheikh, 2011) such as inadequate expectations regarding sleep duration, sleep settings ("child must always sleep alone"), and coping with child's awakenings after sleep onset. Inadequate parenting behavior may also hinder the development in their children of self-soothing abilities (Touchette et al., 2012). In these regards, and given that parenting styles remain rather stable over time, teenagers' psychological functioning may reflect family functioning. Indeed, previous research has shown that teenagers' sleep and psychological functioning do partly depend upon family functioning (cf. Bell and Belsky, 2008), family sleep (Brand et al., 2009a, 2009b; Kalak et al., 2012a, 2012b; Bajoghli et al., 2013), and on the parenting style experienced (Brand et al., 2009b, 2011). In these respects, Table 2 shows that poor sleepers had the lowest scores for family environment, as compared to normal and poor sleepers (though the difference was not significant). Third, pre-schoolers' sleep patterns may reflect a preclinical state of later psychological difficulties or psychiatric disorders. This assumption is partly supported by previous research (Hatzinger et al., 2008, 2010, 2013a, 2013b, 2014) indicating an association between poor sleep and increased cortisol secretion (Hatzinger et al., 2008, 2010) as well as an association with more psychological difficulties cross-sectionally (Hatzinger et al., 2008, 2010) and longitudinally (Hatzinger et al., 2013a, 2013b, 2014). It is also supported by the observation that, for example sleep disruptions during infancy, along with frequent crying and feeding difficulties, were associated with increased behavioral difficulties during childhood (Hemmi et al., 2011). Fourth, Fichter et al. (2009) showed that sleep disturbances, along with somatic symptoms, fatigue, irritability, depression, anxiety, worry and phobia during childhood and adolescence predict the risk of suffering from psychiatric disorders in adulthood.

The present pattern of results might also, however, have emerged due to further latent and unassessed factors such that participants' sleep as pre-schoolers and psychological functioning as adolescents are not causally related. Thus, several studies show that neuronal changes during adolescence are dramatic (Spear, 2000; Paus et al., 2008) and these are associated with changes in sleep patterns (Colrain and Baker, 2011; Kurth et al., 2010), and with the emergence of prodromal psychiatric symptoms (Paus et al., 2008; Correll, 2010).

The second issue was that, against expectations, *normal*, but *not good* sleepers at the age of 5.4 years had the more favorable psychological functioning at the age of 14 years. Again, the evidence from this study cannot clarify the underlying mechanisms. We note, however, that Friedman et al. (2009) reported a decrease in sleep problems from about 70% at pre-school age to about 33% by the age of 16 years, suggesting therefore a shift towards a normalization of sleep problems. On this basis one might speculate that a distinction made between normal and good sleepers at pre-school age is inappropriate when applied to psychological functioning in adolescence. Indeed, as Table 2 shows, positive scores for psychological functioning have repeatedly been observed among both good and normal sleepers. Therefore, one might conclude that dichotomizing instead between poor and normal-to-good sleepers would have better reflected adolescents' psychological functioning and sleep.

As regards the research question focusing on the association between sleep and physical activity, no differences between the three groups were observed. We note that studies in the field are predominantly cross-sectional (Brand et al., 2010a, 2010b; Dworak et al., 2008; Gerber et al., 2010; Lang et al., 2013), or longitudinal only in the short term (e.g., Kalak et al., 2012a, 2012b). Further, whereas there is a dearth on studies investigating the influence of sleep on exercise behavior (Chennaoui et al., 2014), no research has focused so far on the study question to what extent objectively assessed sleep might be associated with exercise behavior at very long term. Here, we observed a zero-association. Moreover, a large number of studies show that adolescents' exercising behavior can be influenced by a broad variety of social, environmental and motivational factors. For example, Madsen et al. (2009) showed that female adolescents' exercise behavior varied as a function of age (i.e., exercising decreased from the age of 11 to the age of 16, and increased again from the age of 16 to the age of 19 years) and of perceived parental exercise behavior (that is, the more adolescents thought that their parents were exercising regularly, the more they themselves exercised).

Despite the intriguing findings, several limitations warrant against overgeneralization of the results. First, the sample size was small; accordingly, one might speculate the statistical procedures were underpowered. A larger sample size could well have allowed detection of further differences between the three groups. A larger sample size would also have allowed introduction of further factors such as gender and current exercise behavior. Second, 55% of the initial sample of 67 5.4 years old children agreed being followed up. Accordingly, again, the sample size and the sample characteristics do preclude a generalization of the present pattern of results. Third, the nature of the developmental 'transmission belt' between sleep in childhood and psychological functioning in adolescence remains unclear. In these respects, we underline that objectively assessed sleep variables at the age of 5.4 years were not disconnected from participants' psychological functioning during that assessment time. Therefore, further factors such as internalizing and externalizing problems, hyperactivity behavior or prosocial behavior should have been introduced in the equations as possible confounders. We are aware of this limitation. On the flip side, first, statistical constraints would not have allowed further meaningful computations while introducing a set of confounders, leading therefore to zero-associations, and second, most importantly, the aim of the present study was to associate sleep variables and psychological functioning over time, to investigate the predictive value of objective sleep parameters for sleep and psychological functioning during adolescence and to put the present data among the sparse research focusing on the predictive value of sleep during

pre-school years for sleep and psychological functioning during adolescence. Therefore, even while keeping in mind that sleep parameters at the age of 5.4 years are not independent from psychological functioning at that period of time, in our opinion, it would have been out of scope to introducing all possible confounders. Moreover, this issue might be addressed at virtually every study in the field of associations of sleep over time. Fourth, no group differences were found as regards current subjectively assessed sleep. In these respects, again, following Friedman et al. (2009), we speculate that sleep difficulties change over time, and that current issues such as stress (Gerber et al., 2014), vocational concerns and life style behavior (Dahl and Lewin, 2002; Brand and Kirov, 2011), exercise behavior (Brand et al., 2010a, 2010b), critical life events (McKinley et al., 2012), and substance use (Gromov and Gromov, 2009) have a greater influence on current sleep difficulties than objectively assessed sleep patterns nine years earlier. A further possibility, however, is that there really is no linear association between sleep at the age of five and at fourteen years. In this respect, we further speculate that associations between the two sleep measurements might have been observed, if also at the second time point objective sleep-EEG variables could have been assessed. Further, 14-years old participants did not undergo further objective sleep assessments. Accordingly, the study would have been even more representative, if objective sleep parameters assessed at the ages of 5.4 years and 14 years could have been compared.

5. Conclusions

The present pattern of results suggests that objectively assessed sleep at the age of five years predicts a broad range of psychological functioning at the age of 14 years such as perceived stress, mental toughness, self-perception, feelings and emotions, peer relationship and school environment, along with educational performance, whereas it is unrelated to current subjectively assessed sleep.

Role of funding

The present longitudinal study was performed without external funding.

Contributions

SB, MH, AvW, SP, KvK, SS, and EHT conducted the first cross-sectional and longitudinal studies; SB, MH, MB, CS, AvW, SP, KvK, SS, and EHT designed the follow-up study and wrote the study protocol. MB and CS gathered the data. SB performed the statistics and wrote the draft of the manuscript. All authors commented on the first draft. SB finalized the manuscript.

Conflict of interest

All authors declare no conflict of interests.

Acknowledgment

We thank Marielle Koenig and Vladimir Djurdjevic for sleep-EEG analysis. Moreover, we thank Nick Emler (University of Surrey, UK) for proofreading the manuscript.

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